



International Civil Aviation Organization

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Advisory Group (RASMAG/13)**

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Agenda Item 3: Reports from Asia/Pacific RMAs and EMAs

Treatment of Flight Levels Crossed in the Assessment of Vertical Collision Risk

(Prepared by Federal Aviation Administration)

SUMMARY

This working paper presents a description of the treatment of flight levels crossed in the assessment of vertical collision risk.

1. Introduction

1.1 The estimation of flight levels crossed for operational errors or risk bearing deviations involving whole numbers of flight levels is needed to assess the vertical collision risk in airspace. Paragraph 5.5 of reference 1 provides a method to estimate the flight levels crossed and the time spent at incorrect flight levels for the estimation of collision risk.

1.2 Depending on the assumed speed of the aircraft involved in the operational error, the addition of the flight levels crossed accounts for the additional risk associated with the time spent passing through flight levels in error. This information paper contains a methodology to estimate the portion of collision risk attributed to crossing flight levels without clearance.

2. Background

2.1 The FAA Technical Center has made significant contributions to the development of the RVSM implementation guidance material, ICAO Doc 9574. The FAA Technical Center also contributed to the document which detailed the vertical risk assessment methodology used for the RVSM in the North Atlantic (NAT) Minimum Navigation Performance System (MNPS) airspace (reference 1). This document describes the methodology used to estimate both the technical and operational vertical collision risk.

2.2 The operational risk is estimated using the time spent erroneously by an aircraft at or near to flight levels that may be occupied by other aircraft. This time in combination with the chance that another aircraft might be occupying the flight level to which the erring aircraft is proximate yields the estimate of collision risk. The process for estimating operational risk is the same for oceanic and domestic airspace, despite differences between oceanic and domestic airspace operating environments.

2.3 In oceanic or enroute airspace, much of the time spent at incorrect flight levels is attributed to aircraft maintaining the incorrect flight level for some duration. In these cases, it is likely the aircraft crossed flight levels prior to maintaining the incorrect flight level, however, the time spent at the maintained flight level is more significant for the calculation of risk than the time spent crossing flight levels.

2.4 In domestic airspace, where radar coverage prevails, air traffic control (ATC) may detect an operational error before an aircraft maintains the incorrect flight level for any duration. In these cases, the aircraft may have crossed flight levels, triggering an ATC response and action, resulting in zero time spent at an incorrect flight level. Therefore, the time spent crossing the flight levels incorrectly is estimated and included in the calculation of the vertical risk.

2.5 The North American RVSM Scrutiny Group (NAM SG) meets semi-annually to review all events affecting operational and technical risk in North American RVSM airspace. The members of the NAM SG, experts in aircraft operation and provision of ATC service, examine all data available to describe the circumstances surrounding these events. After review of each operational-error event, the NAM SG assigns a time and numbers of flight levels crossed that the erring aircraft spends in proximity to flight levels other than that to which it was cleared properly by ATC. These NAM SG examinations have shown consistently that the near real-time surveillance and communications characteristic of North American domestic airspace allow ATC to quickly identify and resolve most operational-error events occurring in RVSM airspace. Thus, the overall NAM RVSM risk estimate produced at each SG meeting is not dominated by time spent by aircraft at incorrect flight levels, in contrast to oceanic-airspace risk estimates with which the FAA is familiar where ATC relies on position-reporting to uncover operational events. The estimate of time spent for crossing flight levels without ATC clearance contributes to the operational risk estimate.

3. Discussion

3.1 Equation 1 is the vertical collision risk model in terms of the number of fatal accidents per flight hour due to loss of vertical separation:

$$N_{az} = P_z(S_z)P_y(0)\frac{\lambda_x}{S_x}\left\{E_z(\text{same})\left[\frac{|\overline{\Delta V}|}{2\lambda_x} + \frac{|\dot{y}|}{2\lambda_y} + \frac{|\dot{z}|}{2\lambda_z}\right] + E_z(\text{opp})\left[\frac{2|\overline{V}|}{2\lambda_x} + \frac{|\dot{y}|}{2\lambda_y} + \frac{|\dot{z}|}{2\lambda_z}\right]\right\} \quad (1)$$

The individual parameters for the model and their definitions are given in Table 1.

CRM Parameter	Description
N_{az}	Number of fatal accidents per flight hour due to loss of vertical separation.
S_z	Vertical separation minimum.
$P_z(S_z)$	Probability that two aircraft nominally separated by the vertical separation minimum are in vertical overlap.
$P_y(0)$	Probability that two aircraft on the same track are in lateral overlap.
λ_x	Average aircraft length.
λ_y	Average aircraft wing-span.
λ_z	Average aircraft height with undercarriage retracted.
\hat{S}_x	Length of longitudinal window used to calculate occupancy.
$E_z(\text{same})$	Same direction vertical occupancy.
$E_z(\text{opp})$	Opposite direction vertical occupancy.
$ \overline{\Delta V} $	Average absolute relative along track speed between aircraft on same direction routes.

$ \bar{v} $	Average absolute aircraft air speed
$ \bar{y} $	Average absolute relative cross track speed for aircraft nominally on the same track.
$ \bar{z} $	Average absolute relative vertical speed of an aircraft pair that have lost all vertical separation.

Table 1: Parameters of the Reich Collision Risk Model for the Vertical Dimension.

3.2 The vertical collision risk model (equation 1) cannot be used directly to calculate the risk of crossing a flight level without clearance. The expression must be re-arranged to give the collision risk per flight level crossed rather than the collision risk per flight hour (reference 1).

3.3 It is assumed that the aircraft lateral path keeping performance is no worse than that for an aircraft in level flight, (e.g. the same $P_y(0)$ value used in equation (1) can be used for the flight levels crossed risk estimate).

3.4 To estimate the risk associated with climbing/descending through a track, an estimate of the rate of climb/descent must be made. Assumptions of aircraft climb/descent rate for various scenarios are needed. For example, the NAM SG agreed to assign descent rates of 1,000 ft/min (10 knots) to aircraft when a drift speed is appropriate, 1,500 ft/min (15 knots) to aircraft when normal descent is appropriate, and 2,500 (25 knots) ft/min to aircraft for rapid descent in NAM airspace. The assumptions for the rate of climb in NAM are 500 ft/min (5 knots) to aircraft when a minimum climb rate is appropriate, 750 ft/min (7.5 knots) to aircraft for normal climb rates, and 1,250 ft/min (12.5 knots) to aircraft for expedite climb rates. These assumptions, along with others made by the NAM SG are detailed in Appendix A.

3.5 Reference 1 provides two models for estimating the time spent crossing incorrect flight levels. The first model, for climb/descent rates less than or equal to 4,000 ft/min (or 40 knots), is applicable to all of the NAM SG assumed climb/descent rates. The second model described in reference 1 is used for pressurization failures which can result in descent rates in the region of 4,000 ft/min to 6,000 ft/min (approximately 40 to 60 knots).

3.6 The vertical collision risk model (1) assumes the collision risk between two aircraft of length λ_x , wingspan λ_y and height λ_z is equivalent to the collision risk between a particle and a rectangular box of dimensions $2\lambda_x \times 2\lambda_y \times 2\lambda_z$ (reference 1). The number of collisions per unit time (C) is given by:

$$C = N_x P_y P_z + N_y P_z P_x + N_z P_x P_y \quad (2)$$

Where N_x, N_y, N_z are the frequencies of loss of separation in the x, y and z dimensions per unit time and the values $P_y, P_x,$ and P_z are the probability of loss of separation in the x, y and z dimension (reference 1).

3.7 In equation (1) the unit of time is one hour. To estimate the risk of flight levels crossed, the time, t_z , is the time during the transition when two aircraft are in vertical overlap, e.g. within a distance $\pm\lambda_z$ of each other (reference 1). t_z is given by:

$$t_z = \frac{2\lambda_z}{|\bar{z}|} \quad (3)$$

3.8 During the time of transition of flight levels, the probability of loss of vertical separation (P_z) is 1, i.e. the aircraft are in vertical overlap. The frequency of loss of vertical separation per t_z , (N_z), is also 1, e.g. the loss of vertical separation occurs once for each flight level crossed (reference 1). For the vertical dimension:

$$N_z = P_z t_z \frac{|\bar{z}|}{2\lambda_z} \quad (4)$$

3.9 The probability of loss in the longitudinal dimension during the period t_z is equal to the average time spent in longitudinal overlap in time t_z divided by t_z , e.g. the proportion of t_z spent in overlap in the longitudinal (x) dimension. (reference 1)

$$P_x = \frac{N_x \frac{2\lambda_x}{|\bar{x}|}}{t_z}$$

or

$$N_x = P_x t_z \frac{|\bar{x}|}{2\lambda_x} \quad (5)$$

3.10 Similarly in the lateral dimension:

$$N_y = P_y t_z \frac{|\bar{y}|}{2\lambda_y} \quad (6)$$

3.11 Substituting for (3), (4), (5), and (6) into (2) gives the number of collisions per level transitioned (C_t).

$$C_t = P_x P_y \frac{2\lambda_z}{|\bar{z}|} \left[\frac{|\bar{x}|}{2\lambda_x} + \frac{|\bar{y}|}{2\lambda_y} + \frac{|\bar{z}|}{2\lambda_z} \right] \quad (7)$$

3.12 In this case, P_y is the probability of lateral overlap for two aircraft on the same track, $P_y(0)$. P_x can be calculated from the occupancies used in (1) as it is equivalent to the proportion of the length of an adjacent track occupied by other aircraft. (reference 1).

$$P_x = \frac{\lambda_x}{S_x} (E_z(\text{same}) + E_z(\text{opp})) \quad (8)$$

3.13 Substituting (8) into (7) and using the two values for $|\bar{x}|$ for same and opposite direction traffic, $|\overline{\Delta V}|$ and $|\bar{V}|$, respectively, gives the following expression for the number of collisions per level transitioned (C_t):

$$C_t = P_y \frac{2\lambda_x \lambda_z}{|\bar{z}| S_x} \left[E_z(\text{same}) \left(\frac{|\overline{\Delta V}|}{2\lambda_x} + \frac{|\bar{y}|}{2\lambda_y} + \frac{|\bar{z}|}{2\lambda_z} \right) + E_z(\text{opp}) \left(\frac{2|\bar{V}|}{2\lambda_x} + \frac{|\bar{y}|}{2\lambda_y} + \frac{|\bar{z}|}{2\lambda_z} \right) \right] \quad (9)$$

3.14 Some sample calculations of C_t for assumed climb/descent rates given in paragraph 3.4 for the NAM RVSM airspace are shown in Table 2 using the following parameter values; $P_y(0)=0.0525$, $E_z(\text{same}) = 0.4250$, $E_z(\text{opp})=0.1155$, $S_x=120$ nm, $\lambda_x=0.0199$ nm, $\lambda_y =0.0171$ nm, $\lambda_z=0.0058$ nm, $|\overline{\Delta V}|=13$ knots, $|\bar{V}|=480$ knots, $|\bar{y}|=5$ knots, and $|\bar{z}|=1.5$ knots. The results in table 2 show the risk decreases as the assumed climb/descent rate increases, this is

because at higher speeds the transitioning aircraft passes through a potentially occupied flight level faster than lower speeds.

Climb/Descent Rate	C_t for RVSM Airspace
Descent Drift (10 knots)	3.506×10^{-5}
Descent Normal (15 knots)	2.495×10^{-5}
Descent Rapid (25 knots)	1.686×10^{-5}
Climb Minimum (5 knots)	6.540×10^{-5}
Climb Normal (7.5 knots)	4.517×10^{-5}
Climb Expedite (12.50 knots)	2.899×10^{-5}

Table 2: Sample Estimates of Collision Risk per Uncleared Flight Level Crossed

3.15 The risk in collisions per level crossed without clearance (C_t) can then be converted to fatal accidents per flight hour by multiplying by the number of levels crossed and dividing by an estimate of the total system flight hours (reference 1). A further multiplication of two is required to convert from collisions to accidents, thus:

$$N_{az} = 2 \cdot \frac{C_t}{T} \quad (10)$$

where T = Annual flying hours in the airspace

3.16 As an example, using the value in Table 2 for a normal descent rate of 15 knots, and assuming 10.8 million flying hours in US Domestic airspace, each RVSM flight level being crossed without clearance adds approximately 4.62×10^{-12} fatal accidents/flight hour to the overall collision risk in the system.

4. Actions by the Meeting

4.1 The meeting is invited to note the information presented in this paper.

References

1. North Atlantic (NAT) Systems Planning Group (SPG) Mathematicians' Working Group (MWG), "Risk Assessment and System Monitoring for the Verification and Operation of a 300 m (1000 ft) Vertical Separation Minimum in the Minimum Navigation Performance Specifications Airspace of the North Atlantic Region", Draft Version 2.1, 23 August 1996.

Appendix A

LARGE HEIGHT DEVIATION DATABASE CONTENTS AND ANALYSIS

DATA SOURCES

Source	Database	Schedule	Current Disposition	
			From	To
ATQA	PD	Monthly	Jan 2000	Current
	OE/OD	Monthly	Jan 2000	Current
	NMAC	Monthly	Jan 2000	Current
ASIAS	ASRS	Quarterly	Jan 2000	Current
Facility Reports	7110.82C	Intermittent	Jan 2000	Current

Geographical Locations – data supplied by applicable ARTCCs and FIRs

DESCRIPTION OF CRITERIA

Cleared Flight Level – the flight level at which the pilot was cleared or currently operating (eg, Aircrew accepts a clearance intended for another aircraft and ATC fails to capture the read back error or aircrew conforms to a flawed clearance delivered by ATC)

Reference Flight Level – The altitude that would have provided at least the minimum separation (vertical or horizontal) required

That flight level from which the Height Deviation is calculated; this level may be different from the Cleared Flight Level and must often be determined by the Scrutiny Group operational experts from the data in the Large Height Deviation report

Event Flight Level – the flight level of error, the incorrect altitude of operation for an identifiable period of time without having received an ATC clearance

Height Deviation – any altitude variation of 300ft or greater from the assigned altitude, these variations can be the result of turbulence, equipment malfunction, ATC loop errors, etc.

ATC Loop Errors – any incident where there is a misunderstanding between the pilot and the controller, failure to properly coordinate altitude information or unable to maintain situational awareness

Total Deviation – the total amount of feet between the altitudes of current operation prior to the deviation and the point at which the aircraft is once again under ATC supervision, a deviation that resulted in an increase of altitude will be recorded as a positive number, a deviation that resulted in a decrease of altitude will be recorded as a negative number

Hazard Zone – 300ft buffer zone above and below each flight level (Diagram 1-A)

Duration - length of time that an aircraft was level at an altitude that was not cleared by air traffic control, duration will be recorded in one second increments (Diagram 1-A)

Levels Crossed – the total number of flight levels between the point that the aircraft exits the cleared flight level and is once again under ATC supervision

Levels Final – the cleared flight level after the error/deviation

Code – a category and a subcategory assigned to each event (Diagram 1-B)

Rate of Descent

Drift	1000 ft per minute
Normal	1500+ ft per minute
Rapid	2500+ ft per minute

Rate of Climb

Minimum	500
Normal	750
Expedite	1250

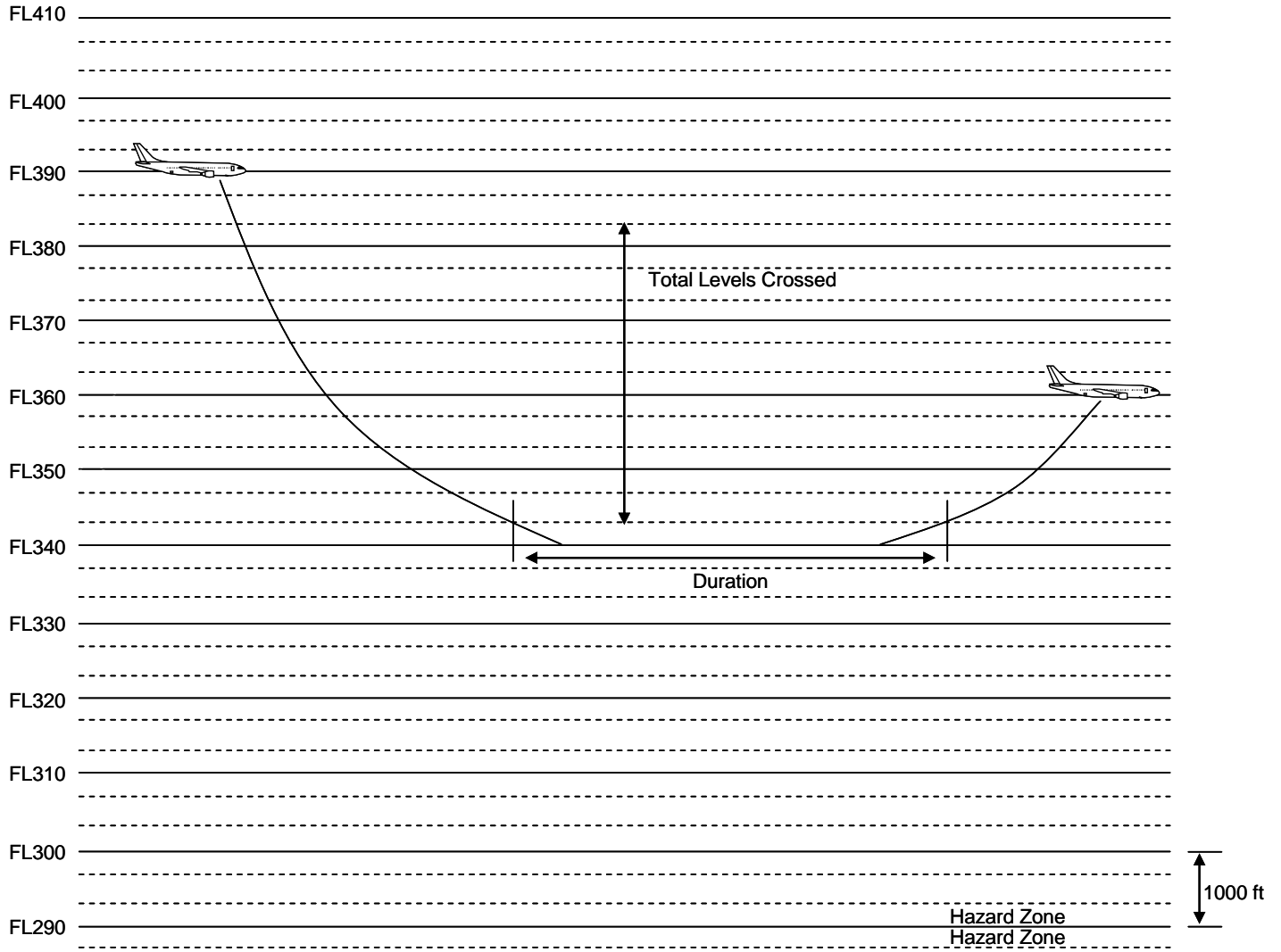
Key Words and Criteria Used to Search Databases

Descen	*TCAS*	Event flight level > 270 and < 430
deviat	*turbulence*	> 01/01/2000 to current
failure	*weather*	
RVSM		

** Matches any number of characters*

1-A

RVSM Flight Levels



1-B

RVSM Codes - Vertical Errors

Category	Description
1	Final level within RVSM airspace
2	Final level above RVSM airspace
3	Final level below RVSM airspace
Subcategory	Description
A	Contingency action due to engine fault
B	Contingency action due to pressurization failure
C	Contingency action due to other cause
D	Failure to climb/descend as cleared
E	Climb/descent without ATC clearance
F	Non-RVSM
G	ATC FL re-clearance resulting in a loss of lateral or longitudinal separation
H	Deviation due to TCAS
I	Aircraft unable to maintain level
J	ATC failure to correctly record, coordinate, or follow through on FL changes and/or other clearances
K	Aircrew not maintaining level as cleared
L	ATC failure to capture incorrect read back of control instructions, fails to maintain situational awareness, or fails to resolve transposed call signs
M	Actions taken due to mechanical or equipment failure
O	Other
W	Weather